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Erosion of Iron-Chromium Alloys by Glass Particles

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NASA

Summary

The material loss upon erosion was measured for several iron-chromium alloys. Two types of erodent material were used: spherical glass beads and sharp particles of crushed glass. For erosion with glass beads the erosion resistance (defined as the reciprocal of material loss rate) was linearly dependent on hardness. This was in accordance with the erosion behavior of pure metals, but contrary to the erosion behavior of alloys of constant composition that were subjected to different heat treatments. For erosion with crushed glass, however, no correlation existed between hardness and erosion resistance. Instead, the erosion resistance depended on alloy composition rather than on hardness and increased with the chromium content of the alloy. The difference in erosion behavior for the two types of erodent particles suggested that two different material removal mechanisms were involved. This was confirmed by SEM micrographs of the eroded surfaces, which showed that for erosion with glass beads the mechanism of material removal was deformation-induced flaking of surface layers, or peening, whereas for erosion with crushed glass it was cutting or chopping.

Introduction

In spite of the recent interest in the erosion of materials by solid particles and its mechanisms (for an excellent review, see ref. 1), little work concerning the effect of material properties on erosion resistance has been reported. The available literature consists mainly of comparative studies of the erosion resistance of various materials (refs. 2 to 6). The effect of the microstructures of 1020 and 1075 steels on their erosion behavior was studied by Levy (ref. 7).

In a study of the effect of various heat treatments on the erosion resistance of 1045 steel (ref. 8), it was found that although quenching and formation of martensite considerably increase the resistance to erosion with glass beads, they have no observable effect on the resistance to erosion with crushed glass, which represents more realistic erosion conditions. Similar results were obtained for heat treatment of the 6061 aluminum alloy, where solution heat treatment causes a substantial increase in resistance to erosion with glass beads (ref. 9) but has no effect on resistance to erosion with crushed glass. There thus seems to be little hope of improving resistance to erosion with sharp particles by heat treating. Another approach to this problem is presented herein, namely, increasing erosion resistance by changing the chemical composition of the eroded material.

The materials selected for this study were iron-chromium alloys. These alloys are the basis for stainless steels, and thus studying their erosion behavior may give useful information for applying this important class of construction materials in erosive conditions. Also, this study may indicate the extent of the usefulness of chromium diffusion coating, an established industrial process (ref. 10), for protection against erosion.

The friction and wear behavior of these alloys in contact with an abrasive grit of silicon carbide (as well as with themselves) was investigated by Miyoshi and Buckley (ref. 11). They found that the height of grooves formed in these materials as a result of sliding against silicon carbide depends on the chromium content of the alloys and reaches a minimum at 14 wt % chromium. These results were interpreted as due to atomic size misfit between iron and chromium, following Stephens and Witzke (ref. 12). It was of interest to compare these findings with erosion results.

Materials

The alloys used in this investigation were prepared from 99.9 percent pure iron and 99.7 percent pure chromium. The starting materials were placed in zirconia molds and then induction melted in an argon atmosphere. Alloys containing 1, 9, 14, and 19 wt % chromium were used. Before samples were prepared, the alloys were annealed in a vacuum furnace at 460° C and a pressure of 34 μPa (4.5×10^{-3} torr) for 5 hours.

Two types of erodent particles were employed: glass beads with an average diameter of 15 μm and crushed glass. Figure 1 shows micrographs of the two types of erodent particles.

X-ray diffraction patterns were taken by using a copper source operated at a voltage of 45 kV and a current of 40 mA with a nickel filter.

The Rockwell A hardness values of the samples are given in table I. Hardness was highest for the Fe–19Cr alloy. To check whether this variation in hardness was due to formation of intermetallic compounds, X-ray diffraction patterns of the samples were taken (fig. 2). These diffractograms, as well as computer analysis of the diffraction results, show that the X-ray diffraction patterns of the various Fe–Cr alloys were essentially identical to the X-ray pattern of pure iron. In other words, no intermetallic compound was observed and the alloys formed a series of solid solutions. The variation in hardness was thus due to solid solution hardening and softening effects.

Experimental Procedure

The hardness of the samples was measured by means of the Rockwell A hardness test. This test, rather than a microhardness test, was selected to eliminate the possibility of erroneous hardness values due to specimen preparation.

Specimens were eroded in an industrial sandblasting apparatus. Argon at a pressure of 0.54 MPa was used as the driving gas in order to minimize corrosion effects. The nozzle diameter was 1.18 mm. The specimen surface was perpendicular to the stream of particles and at a distance of 13 mm from the nozzle. The erodent particle velocities and flow rates under these conditions were measured by Rao et al. (ref. 13) and reported to be 101 m/sec and 0.76 g/sec for glass beads and 68 m/sec and 0.26 g/sec for crushed glass. Reproducible mass-loss results were obtained with a variation not exceeding ± 3 percent.

Results and Discussion

The data for erosion with glass beads are also listed in table I and plotted in figures 3 and 4. The most notable feature of the results is the existence of a linear relation between hardness and erosion resistance. Previous studies (refs. 2, 8, and 9) show no correlation between hardness and erosion resistance for alloys of constant composition subjected to different heat treatments. On the other hand, a comparative study of the erosion of different pure metals with angular silicon carbide particles (ref. 2) yielded a relation between hardness and erosion resistance.

The results expressed in terms of the volume of the material removed are presented in figure 3. Comparison with the results obtained by Miyoshi and Buckley (ref. 11) for the abrasion wear of iron-chromium alloys by silicon carbide (fig. 5) shows a considerable similarity as well as some differences. Thus the groove height in abrasion reached a minimum, and so did the material loss in erosion. These minima, however, seem to appear at somewhat different compositions. Also, the erosion rate for the Fe–1Cr alloy was found to be higher than that of pure iron, whereas no such effect was observed by Miyoshi and Buckley.

For erosion with crushed glass, no correlation was found between hardness and erosion resistance (fig. 6). Rather, the main factor dominating the resistance to erosion with crushed glass seemed to be the chromium content of the alloys. This is an encouraging observation since it provides us with a means of improving the erosion resistance, namely, alloying.

The different effects of chemical composition and hardness on resistance to erosion with glass beads, as compared with erosion with crushed glass, are another manifestation of the fact that two different material removal mechanisms are involved in these two cases. As was already pointed out for the erosion of 1045 steel (refs. 8 and 14) and 6061 aluminum alloy and copper (ref. 14), the main mechanism of material removal for erosion with glass beads is deformation-induced flaking of surface layers, or peening; whereas for erosion with sharp particles, it is cutting or chopping. This can be clearly seen in the SEM micrographs of the surface of the Fe–9Cr alloy eroded by these two types of erodent particles (fig. 7).

Conclusions

The main conclusion of this study of the material loss upon erosion of several iron-chromium alloys is that the resistance of some materials to erosion with sharp particles could be improved by changing their composition. This is in contrast to mechanical and heat treatments, which were previously shown to have little or no effect on resistance to erosion with crushed glass.

Another finding is that the resistance of iron-chromium alloys to erosion with spherical particles increased linearly with hardness. This is in accordance with the erosion resistance of pure metals, but contrary to results obtained for alloys of constant composition that were subjected to different heat treatments.

For erosion with sharp angular particles, however, there was no correlation between hardness and erosion resistance. In this case erosion resistance depended on the alloy composition and increased with chromium content.

The difference in behavior for the two types of erodent particles demonstrated once again that the material removal mechanisms in these two cases are different. For spherical erodent particles the mechanism was deformation-induced flaking of surface layers, whereas for sharp erodent particles it was cutting or chopping.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, April 25, 1984

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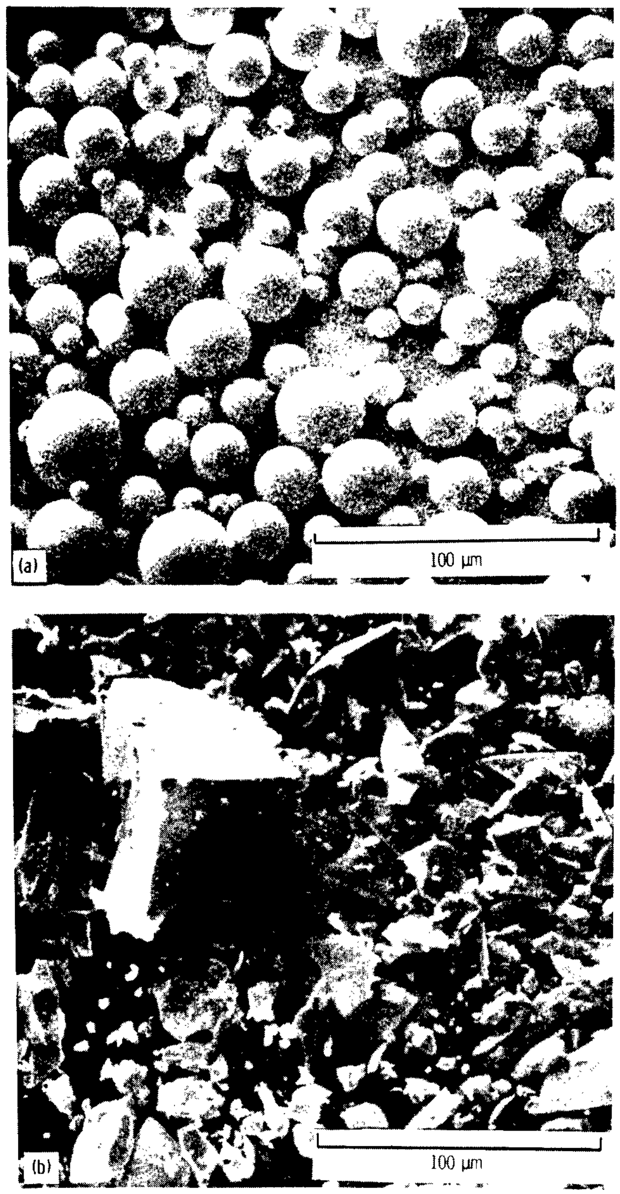
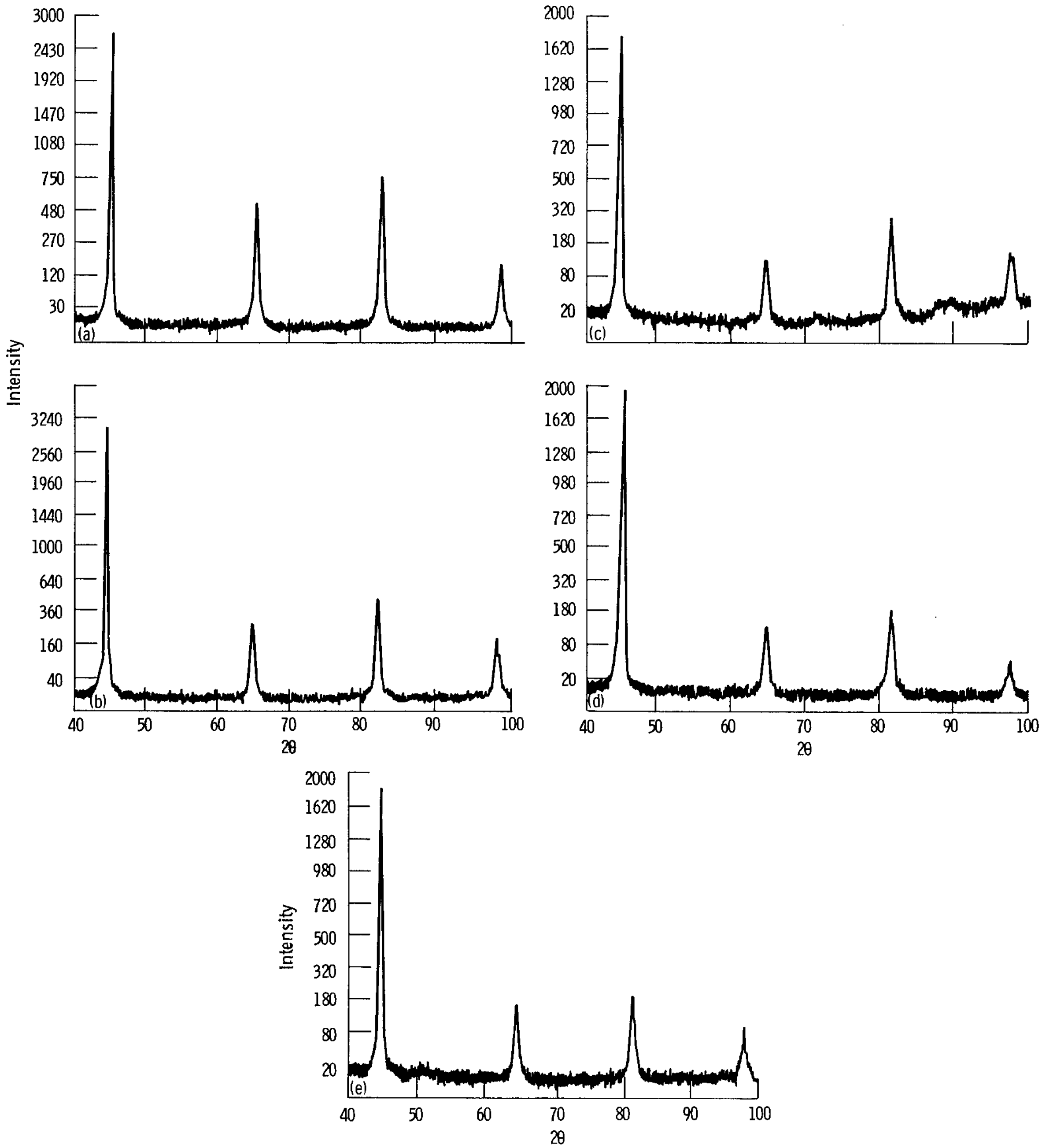
TABLE I.—HARDNESS AND EROSION DATA OF Fe-Cr ALLOYS
OF DIFFERENT COMPOSITIONS

Alloy	Hardness (Rockwell A)	Material loss in 15-min erosion test with glass beads			Material loss in 15-min erosion test with crushed glass		
		Mass, mg	Atoms, g-atom	Volume, mm^3	Mass, mg	Atoms, g-atom	Volume, mm^3
Pure Fe	32	46.0	0.000824	5.84	41.3	0.000739	5.25
Fe-1Cr	30	56.9	.001020	7.29	37.4	.000670	4.79
Fe-9Cr	61	17.7	.000319	2.27	35.8	.000645	4.58
Fe-14Cr	56	22.8	.000412	2.93	33.1	.000598	4.26
Fe-19Cr	40	33.1	.000601	4.27	30.5	.000553	3.94



(a) Glass beads.
(b) Crushed glass.

Figure 1.—SEM micrographs of erodent particles used in this study.



(a) Pure Fe.
(b) Fe–1Cr.
(c) Fe–9Cr.
(d) Fe–14Cr.
(e) Fe–19Cr.

Figure 2.—X-ray diffractograms of the alloys used in this study.

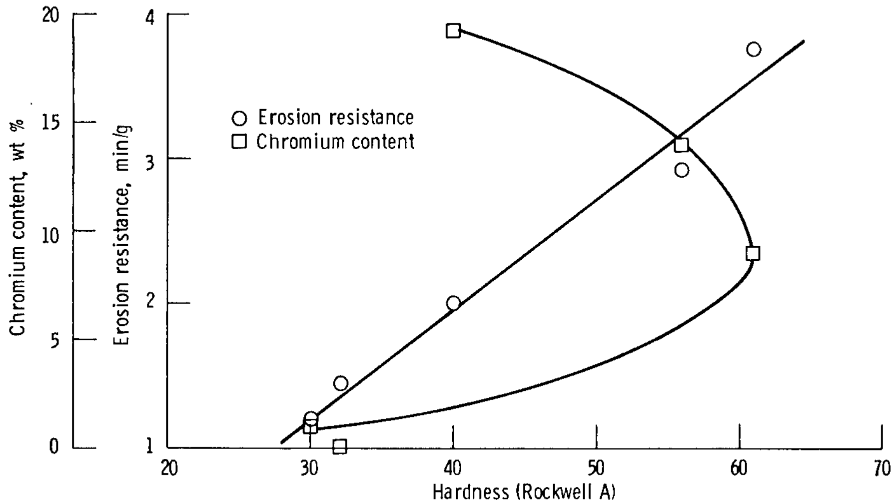


Figure 3.—Erosion resistance and chromium content as functions of hardness for various Fe-Cr alloys eroded by glass beads.

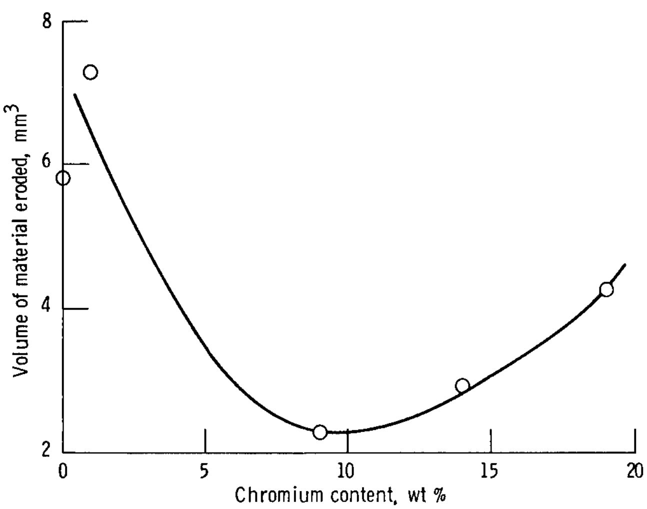


Figure 4.—Material loss as function of chromium content for various Fe-Cr alloys eroded by glass beads.

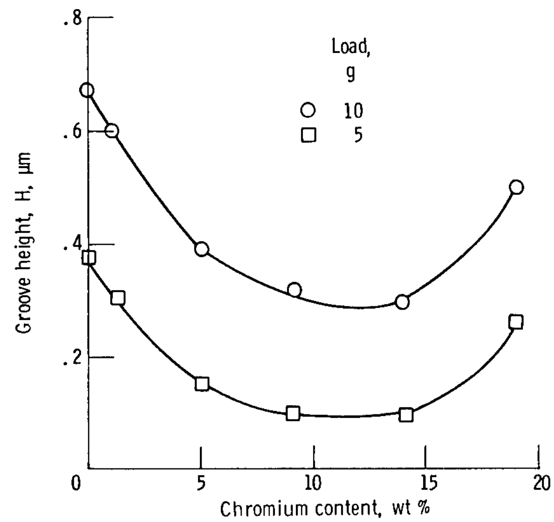


Figure 5.—Height of grooves caused by sliding of silicon carbide rider in mineral oil on Fe-Cr alloys as function of chromium content and load. (From ref. 11.)

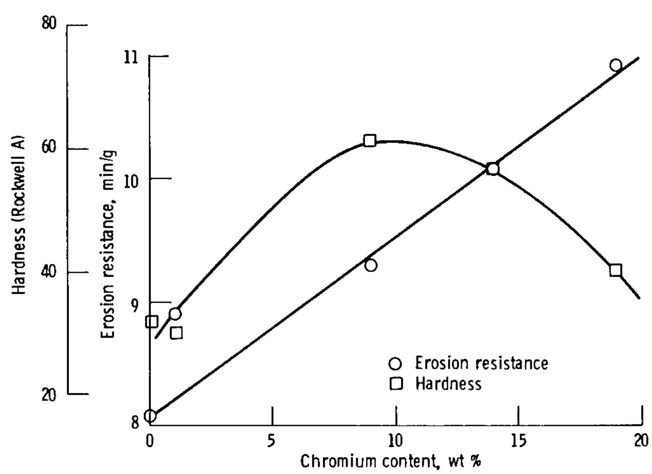
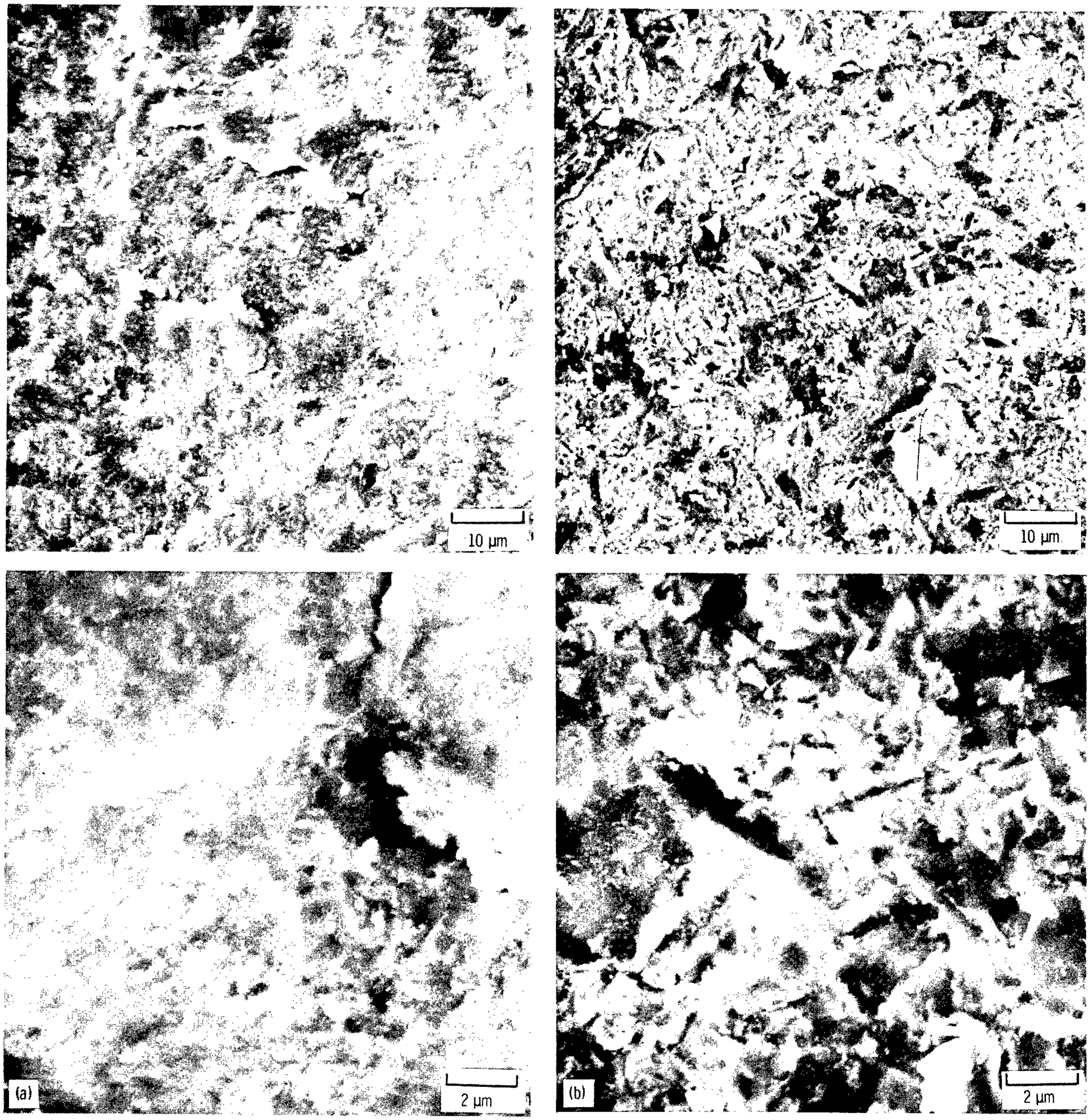


Figure 6.—Erosion resistance and hardness as functions of chromium content for various Fe-Cr alloys eroded by crushed glass.



(a) Erodent, glass beads.
(b) Erodent, crushed glass.

Figure 7.—SEM micrographs of surface of Fe-9Cr alloy eroded with glass beads and crushed glass.

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15. Supplementary Notes

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16. Abstract

The material loss upon erosion was measured for several iron-chromium alloys. Two types of erodent material were used: spherical glass beads and sharp particles of crushed glass. For erosion with glass beads the erosion resistance (defined as the reciprocal of material loss rate) was linearly dependent on hardness. This is in accordance with the erosion behavior of pure metals, but contrary to the erosion behavior of alloys of constant composition that were subjected to different heat treatments. For erosion with crushed glass, however, no correlation existed between hardness and erosion resistance. Instead, the erosion resistance depended on alloy composition rather than on hardness and increased with the chromium content of the alloy. The difference in erosion behavior for the two types of erodent particles suggested that two different material removal mechanisms were involved. This was confirmed by SEM micrographs of the eroded surfaces, which showed that for erosion with glass beads the mechanism of material removal was deformation-induced flaking of surface layers, or peening, whereas for erosion with crushed glass it was cutting or chopping.

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